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Abstract: Mid-air interaction is know to have interesting potential for several interaction contexts, however some problems remain unsolved, including clutching. In this paper we present the concept of sub-space gestures. We describe a participative design user-study, that shows that interacting techniques using a dynamic definition of an imaginary interaction plane made by the user thanks to a gesture, have interesting acceptability. We finally provide some interaction design guidelines for this class of interaction.

Key-words: gestural interaction, mid-air gestures, contactles interaction

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Gestes et sous-espaces. Eléments de design pour l'interaction dans l'air sur écrans distants

Résumé : Ce document présente le concept de gestes réalisés dans des sous-espaces préalablement définis par l'utilisateur. Nous présentons une étude utilisateurs participative montrant l'utilisation et l'acceptabilité d'un tel concept. Finalement, nous donnons quelques recommandations de conception pour ce type d'interaction.

Mots-clés : interaction gestuelle, gestes dans l'air, interaction sans contact

1 Introduction

Grasping the mouse, or touching the pad, is currently, by far, the most common way to start interacting with an application. Leaving such interaction is done by moving fingers away from mouse or pad. Such paradigms imply both proximity between user and interactive system, as well as physical ability to touch the system, or benefit from instrumented interaction. For interaction situations in which distance between user and screen can not be avoided, and instrumented interaction may be difficult to deploy (public displays), or limiting (family in front of connected TV, work meetings, etc ...), mid-air gestural interaction appears to have great potential.
However, such class of gestural interaction still has several drawbacks that are not overcome yet; moreover it is still poorly understood, quite apart from elementary tasks [9]. A common (wrong) approach is to think about mid-air gestures as "touch at a distance", as stated in [11]; this work also mentions that there is no largely accepted proposal for clutching. Using hand postures is a possible solution for clutching in mid-air interaction [10]. However, to our knowledge, no enabling technology can yet handle this in a robust and flexible manner, in spite of strong research effort these past years: issues such as occlusions, calibration problems, compatibility with dynamic viewing distance, are still locks. Another possible solution for enabling clutching in mid-air interaction is to limit interaction to hand positions that belong to a predefined plane [11]. An important weakness of such a potential approach is that no clear knowledge exists about how to choose plane (both location in regard of user, and orientation): If too close, the user may unintentionally cross it, and if too far, may not reach it; vertical plane in the field of view obviously allows "touch-like" systems, but may have low acceptability, due to potential interaction fatigue. Another point is how to activate such plan? which gestures for that? which relation between command gesture and plane location?
For interaction designers, questions of plane localization and dimension in regard of user, gesture for enabling/disabling such planes, hand postures for interacting with it are questions that need some answers: they have a strong impact on any potential interaction technique for such systems. This article presents a user study that provides some elements of knowledge about how users, in a participative design approach, would potentially use such systems.
We generalize, in this article, the idea of predefined plane for mid-air interaction with distant display, and present the concept of *sub-space gestures*, that can be understood, in a first (coarse) approach, as a sub-class of imaginary interfaces [5] adapted to interaction with a display, that also allows simple clutching.
In our results, we show that users validate the idea of a planar sub-space, and that most users that run the experiment instinctively state that plane position is user-defined and dynamic (can be both created and deleted). Interestingly, we show that users have a good spatial perception of created sub-spaces, since most of user-defined creation gestures may be used also for calculating position of plane (including orientation), as well as interaction frontiers. We also show that users easily integrate mental representation of interaction sub-space, since user-defined deletion gestures take plane location into account. Finally, we provide guidelines for interaction designers willing to integrate sub-space gestures in mid-air interaction techniques.

2 Related work

[6] proposes a system that uses 3D input and 2D output. A static extention of the 2D display allow user to performs 3D gestures. There is a direct mapping between the hand above the surface and the output (shadows displayed). As long as the system can detect the user's hands on or above the surface, user can manipulate objects of the 3D scene. In that case, the interaction volume is static. The user has to be near the screen. Moreover, if the user is near from the screen, by moving his hand close to the screen by accident, the gestures will be interpreted.
Few works study contactless interaction, user space perception. [3] provides insights about contactless interaction, mentions that gesture dynamic seem more relevant than hand poses, also that two-handed actions provide a better sense of virtual space. [2] presents a study about precision for close touch-like interaction with a display.
In [8] Kattinakere studies and model a steering law for 3D gestures in above-the-surface layers. To validate the model, four studies have been carried out. Those four studies were tunneling tasks above-the-surface of a screen. Results suggest that a layer should be at least 2 cm thick and that over 35 cm of steering, users make more errors. So if a layer is larger than 35 cm, its height should be increased. This works gives a hint about what type of plane can be used for our system. However, during the studies users were allowed to rest their hand on the surface. In practical situation where this would not be possible, precision may be significantly worse.
In [5], Gustafson proposes a system with no visual feedback. Screen is replaced by short term memory. The user defines dynamically the space in which he wants to interact. This space is defined by the non dominant hand as a reference point. Interactions start with a posture and stop when the user release the pose. Three studies show that multiple strokes sketches are challenging (more time spend, more clutch so memory is degraded), using the non dominant hand as a reference point improves performance. By contrast, in our concept of sub-spaces, the user has a visual feedback as he interacts we a distant screen.

3 Concept of Sub-space interaction

We consider *Sub-space gestures* as interaction gesture that are associated to a specified area of user space (we call it *sub-space area*). This area will have, in the general case, the property to be simple to handle from a numerical programming point of view (i.e. plane, spheres, cubes, etc ...). It can be of arbitrary dimension, depending on application: 1D curve, 2D shape, finite volume. it may relate (but not necessarily) to a physical object, or imaginary representation of it. We think this concept is interesting because it is more specific than standard understanding of mid-air interaction, while obviously leaving quite an interesting design space (shape type, dimension, space localization regarding user and display, multiple spaces, etc...).
Indeed, once the interaction area has been specified, user can clutch easily. A simple test of inclusion (in the case of sub-space volumes), or proximity (in the case of sub-space shapes or curves) can be used for the gesture acquisition system to know if gesture shall be taken into account for interaction, or not.
In the case where area is user-defined, interaction gesture may be used for specifying interaction area through all its geometrical (position/orientation/dimensions/...) parameters, hand posture, or ad-hoc shapes, may either be used for such a command. An application may be set up using some specific class of sub-space area (e.g. a cube), but may leave user(s) with the ability to activate several areas of various dimensions at the same time (whichever the interaction purpose).
Aside from this concept, a lot of questions arise. In the following user study we address, in a participative design approach, some basic points about *sub-space* interaction with distant displays. We do not state anything about the type of content that would be displayed on the screen. Our

concern is to find out which type of sub-space area would be preferred, how users would use gesture to interact with displays through such *sub-space*.

4 User study

Our user study was designed to collect gesture data that could be used to define *sub space* areas and question the user on how it could be used to control a distant display. In order to perform such study without suggesting any solution, we decided to simulate distant screens using a large curved screen (5.96 meters by 2.43 meters) depicted in Figure 1. Using such environment, we are able to project images of displays at different locations regarding the user position as well as varying its dimension. By doing so, we expected to represent daily scenarios in an abstract way such as using a computer screen or a television at home or even larger displays in public places or in collaborative working sessions. The remaining of the section describes our experimental protocol and how it relates to our concept of *Sub-space* interaction. With their agreement, all participant sessions have been videotaped using a Kinect camera in front of the user and a video camera on the side recording a different point of view and sound as shown by Figure 1.

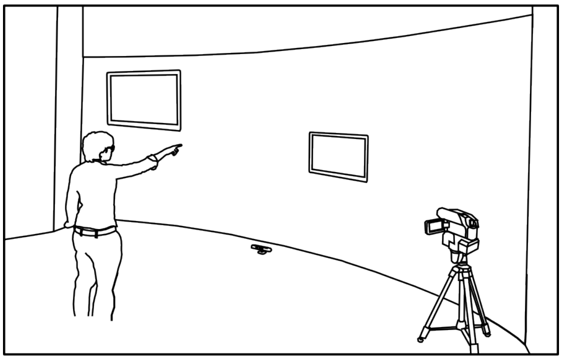

Figure 1: Our apparatus for the study: participants are in front of a large scale display to simulate screens of different sizes at different locations. The sessions are videotaped using a camera on the right side and a Kinect in front of the user.

4.1 Protocol

The experiment was composed of four phases: a questionnaire to profile the user (**phase 1**), a brainstorm phase about methods to interact with distant displays (**phase 2**), repetitive trials to collect user gestures in situation (**phase 3**) and finally a final questionnaire and interview regarding the experiment (**phase 4**).
The first phase was a questionnaire to retrieve users habits about computer, tactile devices and video gaming frequencies of use. They answer on a Likert scale (1 for never, 7 for everyday). We also asked what kind of tactile devices (smartphones, tablets, multitouch screens) and gesture-based devices they had already used (Wiimote, Kinect, Eyetoy, PS Move).
The phase 2 was a brainstorming phase. Participants were asked to tell by what means they would control a distant display. After that, we explained quickly the concept of sub-space interaction, an interaction area to control displays at a distance, and they were asked to define an interactive area. Among their propositions, they had to choose the gesture they preferred.

In the phase 3, participants had to define 90 areas. We projected virtual screens of two different sizes : 32 inches and 55 inches. Each virtual screen were displayed at 15 different positions on the large screen 3 times. They could take a break every 10 trials to avoid fatigue.
For each trial, participants had to define, by a gesture or a posture, an area they thought was the most relevant and comfortable to control the shown virtual screen. Then they had to touch it as if they were interacting with the virtual screen. They were told the virtual screen could be either a computer screen or a television. They could change the gesture or posture when they wanted to. Participants were free to use one hand over the other or even both. We didn't tell them if they had to define fixed areas or areas adapted to their field of view, nor to define planar areas. The only constraint was that they were not allowed to walk. They could turn around if they wanted to.
After the repetitive trials, they were asked to tell which gesture they preferred during the experiment if they had performed different gestures during the study. Then they had to imagine a gesture they would perform to delete an area they have defined.
The phase 4 was a feedback questionnaire. In a first part, users were questioned about the concept of sub-spaces. Whether they thought it is mentally and physically tiring, useful, easy to use and adapted to their everyday life. They had to answered on a Likert scale (1 for "I totally agree" to 7 for "I completely disagree").
Then, participants were asked if they thought that they had made different areas (dimensions, position, orientation) all along the phase 3 and if the position and the size of the virtual screen had an impact on this.
Finally, several situations were proposed: in public, in private, near a screen, far from it, alone, with people, seated, standing, passive and active. Participants had to tell, on a Likert scale, if they would use sub-space interaction in these situations. "In public" refers to situations are present but do not interact. "With people" adresses collaboration situations. "Passive" adresses contexts in which we observe more than we interact. "Active" situation is when interaction is intense.

4.2 Participants

Phase 1 of user study provides elements of user profiling. 18 participants volunteered for the study (4 female). 8 participants worked in HCI. They were between the ages of 22 and 43 (mean: 27.6). Two participants were left-handed and one was ambidextrous. All participants used a PC and large proportion of them used tactile devices almost everyday (mostly smartphones). But a few played video games regularly(see Figure 2). Even if they were not gamers, all of them had already tried and knew 3D gestures using the Wiimote, the Kinect, the Eyetoy or the PS Move.

5 Results

This section presents the results and observations corresponding to the phase 2, 3 and 4 of our study. We decouple our analysis of phase 3 into three parts related to the *Sub-space interaction* basic steps which are: the gestures to create it, how users can interact with it and finally how participants propose to delete it.

5.1 Preliminary questionnaire

We start the brainstorming by asking to the participants "By what means would you control a distant display?" if they could not reach the display physically. From the 18 participants, 50% answered they would use hand gestures or use classical input devices such as a mouse

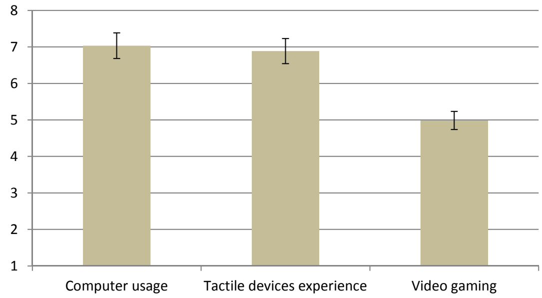

Figure 2: Frequencies of use. *All participants use a computer at least everyday.*

(5 participants) or a remote control(4 participants). 4 users also refer they would use voice commands to control the display content. Then, we invite the subject to take place in front of our large screen and present him an image of a screen simulating a 32 inch physical diagonal. We asked what gestures they would performed to define an interaction area to control such screen and we videotaped their answer. Most participants proposed at least two gestures.However, we noticed afterwards that 8 users used different gestures along the trials of **phase 3** than the one proposed initially. In fact most of them (12 out 18) only used one gesture or invented a new one during the trials. In order to analyze gestures with relevance to the user, we discuss them in the following section considering the repetitive trial phase.

5.2 Interaction space creation gesture

We analyzed the video of each participant and described each gesture performed along the 90 trials of the experiment. To both identify and classify each gesture trial, we used the taxonomy proposed by [7, 1] complemented with the information about which hands were used, their hand postures and the relationship between the location of the gesture and the user field of view or any significant body part.
We choose to discard any isolated gesture performed by the user or slightly different variants from the same gesture. From the 18 users, we found a set of 18 unique gestures among a total of 33 gestures performed by all participants. 50% of the participants used a unique gesture during all the experiment, 23% alternated between both two and three gesture possibilities. Only one user experimented a set of four unique gestures with minor variant imagining different context scenarios while performing the experiment. We noticed that 89 % of users performed iconic dynamic gestures, representing 60 % of all the gestures. They mostly represent rectangular shapes or zooming actions along a line or diagonal delimiting the size of a frame as depicted by Figure 3. 17 % of users use pantomimic gesture such as taking a picture, rolling a fictional ball or drawing on an imaginary tablet. Only one participant defined a semaphoric dynamic gesture identifying the complete round around its body. Static gestures were less preferred compared to dynamic gestures, only three users presented iconic static gestures defining the two corners of a frame. Finally, three subjects used sporadically pointing gestures to identify the screen then interact touching their body or an invisible area in front of them.
Regarding hand usage, 33 % of the participants exclusively defined gestures using one hand, 33 % using both hands and 28 % mixing both approaches while performing the several trials. While all unimanual gestures were mainly done using the dominant hand, most of bimanual gestures described symmetrical movements or poses. Only three users presented gestures with

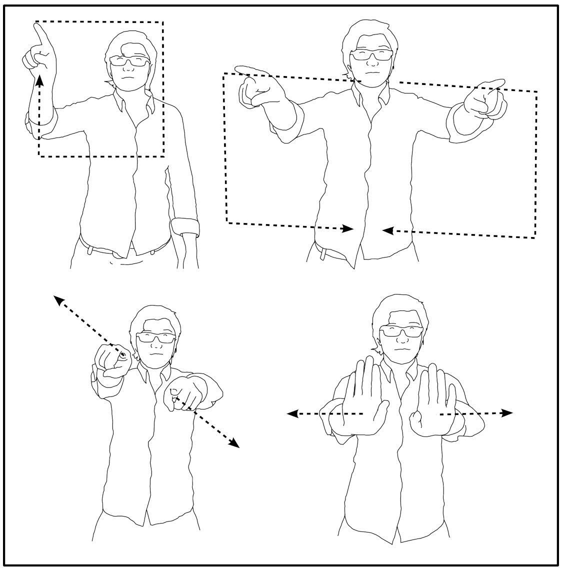

Figure 3: Frequent creation gestures proposed by the user: defining a rectangular area using one or both hands (top) and using an opening gesture in its field of view with diagonal or horizontal symmetric gesture (bottom).

an asymmetrical usage of each hand following the asymmetric bimanual Guiard model [4].
While performing the gestures, we noticed that most of participants used a reduced set of hand poses shown in Figure 4. Index finger pointing to the screen, and mimic of a pencil were prominent among participants (77 %) compared to both L shape (27 %) and open flat hand postures (33 %). The frequent usage of L shape postures using both the index and the thumb finger was to delimit corners of virtual frame or to define an imaginary axis. While performing gestures, hand poses remained unchanged except in one gesture from one user opening hand to specify an action.

About display position influence, we noticed that most of the participant aligned their field of view prior to start the gesture by rotating both the head and body. However, 39 % of the user depicted gestures in a fixed position regarding their body. They usually described well defined

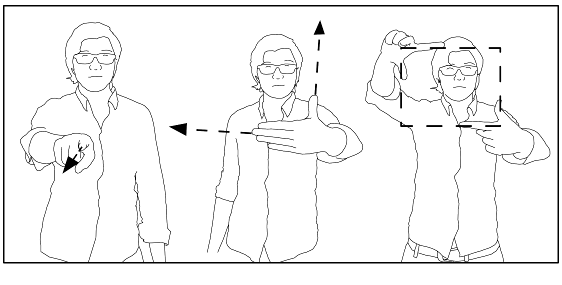

Figure 4: The 3 main hand postures. From left to right: pointing to a given direction, flat hand posture defining a spatial reference, two L hand postures delimiting an area.

horizontal or oblique planes independently of the screen position or field of view. In fact in such scenario, we never noticed that user was looking at his hands while performing the gesture. However the preferred approach (61% of users) was to create vertical planes aligned with the field of view or the projected screen by drawing rectangles or defining static frames. These planes were created drawing a rectangle using one hand or both hands symmetrically (66 %) or using a zooming gesture along a line or a diagonal using dynamic gestures (28%). Circular motions such as circles and waving in front or around the user were less common and only appeared less than 9 % of all gestures. Finally we did not notice a significant influence of screen dimension; most of the user delimited their gesture independently to the screen size even when defined within the field of view. In general, the end of the gesture trajectory created a well defined positioned and sizable area and its orientation seems to be recoverable by analyzing the gesture or combined with the user gaze direction. Looking to the set of the 33 gestures performed by all users, 71 % of them describes an area that can be assimilated to a plane.

5.3 Interacting on the sub-space

For each trial, we asked the participants to touch or interact on the previously defined interaction area. They mainly simulated drawing or small push actions close to the area defined by the sub-space creation gesture as shows Figure 5. While only one user performed the touch action using two hands, most of users touched the imaginary space using their dominant hand. We noticed three different hand poses: pointing using the index finger, pointing using a flat hand and pushing using an open hand with a user %age of 56, 22 and 17 respectively. People using an open or a flat posture tend to push, grab or swipe close to the sub-space definition. While participants pointing using their index finger tried to mimic drawing short scribbles or push small imaginary buttons. Their gestures seem to be more controlled and closer to the area definition compared to gestures performed with another hand posture. Three users performed such touch gesture by mimicking drawing on the non dominant or a body part (near to their pocket) using their dominant hand. While one of them defined its area using a pantomimic gesture simulated by the hand, the other two where the only users just defining the interaction area using a pointing gesture only.

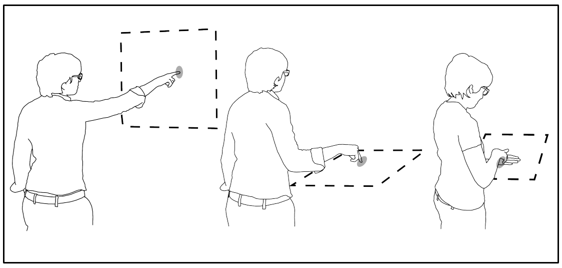

Figure 5: Common touch gestures proposed by the subjects: pointing on a vertical or horizontal imaginary area and touching the non dominant hand as a reference.

5.4 Deleting sub-space

At the end of experiment, we ask participants to propose a delete gesture considering that their interaction zone creation was persistent. Both gestures and comments were videotaped and collected. From the data analysis, only four users proposed more than one alternative gesture

after creating the interaction area using their preferred method. Looking to the 23 gestures collected, we notice a strong usage of pantomimic gestures since most of users materialized the interaction sub-space. 23% of the proposals do not fit in this classification such as leaving the interactive area, waiting for it to disappear, drawing a cross or using the inverse of creation movement. For users that use non dominant hand as a support to interact, the area shall disappear just by removing the hand.
The most frequent pantomimic delete gestures was to mimic pushing the area using a swipe gesture with the dominant hand away from the user body (proposed by 50% of users). Such gesture was assimilated as a horizontal throwing away gesture with some variants such as throwing to the ground or behind their back as illustrated by Figure 6. The second most frequent gesture (23% of participants) was a closing gesture using both hands symmetrically. All these gestures were co-localized with the sub-space creation gesture showing that such imaginary concept is not hard to be accepted and materialized by user.

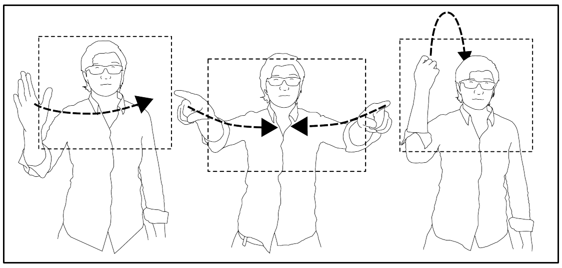

Figure 6: Participants delete gesture proposals: pushing the area with one hand, closing the sub-space using both hand or throwing it away to a given location.

5.5 Final questionnaire analysis

The aim of the final questionnaire was mainly to get feedback from participants about the method. A first part dealt with fatigue and usage. Then we tried to extract contexts of use in which participants would feel comfortable using sub-space gestures. Finally, we asked participants if they had a preferred gesture and compared it to the one they choose before the trials.
Mental and physical acceptation. We had a fairly good feedback concerning the concept of *sub-space* interaction (see Figure 7). Most of the participants believe that this method is compatible with their everyday life, useful, easy to use and not mentally tiring. With reference to tiredness, we ask two questions. They had to answer on a Likert scale. 1 for "Strongly disagree" and 7 for "Totally agree". The first, "In your opinion, is this method mentally tiring?". The mean is 2.5 with a standard deviation of 1.8. The second question about tiredness was "In your opinion, is this method physically tiring?". Generally, participants didn't find this too much tiring with a mean of 3.8 with a standard deviation of 1.6. We think that this is due to the fact that many participants stretched their arms to define the area. To the question "Do you think that this method is easy to use?" the mean on a Likert scale (1 to 7) is 5.6 with a standard deviation of 1.2. And to the question "Would you say that this method is useful?", the mean is 5.2 and the standard deviation is 1.

Contexts of use. We proposed several contexts of interaction and the participants had to answer on a Likert scale if they would or not use sub-space interaction in this contexts. The results of the questionnaire are summarized in Figure 8.

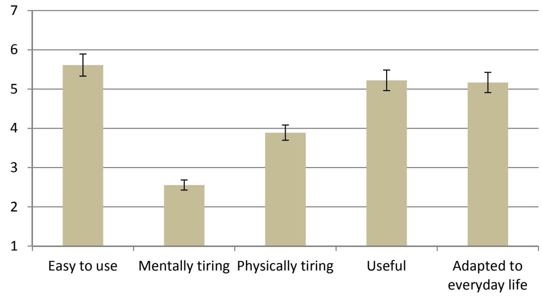

Figure 7: Users opinions about sub-space gestures on various factors, using Likert scale, from 1 ("absolutely") to 7 ("absolutely not").

One can see that the most part of participants won't use sub-space gestures in public places, near a screen or in an active context. Most likely because in public places, this might look strange to move your arms around. If users are next to a screen, classical means as mouse and keyboard could be within reach of the hands. In an active context, where users would have to interact during an intense long period, sub-space gestures would cause physical fatigue.
Contexts as in private, far from a screen, alone and standing are the best rated. With people, seated and passive are quite accepted contexts in which participants could interact thanks to sub-spaces. Those contexts completely describe cases where we want to interact with a distant screen. **Perception of variability**. We questioned users about the perceived influence of basic

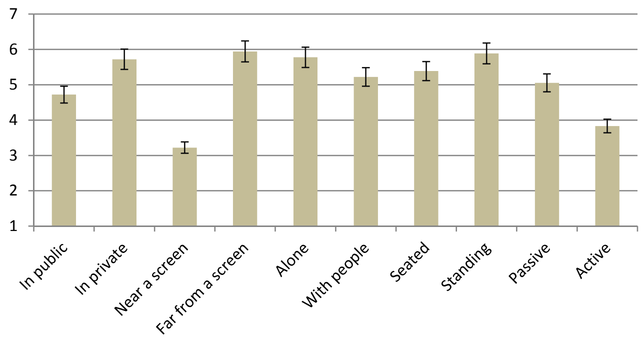

Figure 8: User evaluation on several contexts of use of sub-space gestures, on a Likert scale, from 1 ("I would not use sub-space in that context"), to 7 ("yes, I would use it").

elements of spatiality that may influence interaction: "Do you think you make different areas during the repetitive trials?", "Do you think you were influenced by screen position?", "Do you think you were influenced by screen size?", on a Likert scale (from 1 to 7). Users thought they made different area and that they were influenced by the position and size of the screen.
We also asked what gesture they preferred among the ones they made. More than 94% of the participants preferred a different gesture than the one they chose before the trials.

6 Guidelines

From the experiment, we exhibit the following elements, that we think useful for future interaction technique design.
Make sub-space planar, and dynamic : most of users spontanuously create planar sub-spaces, and take for granted that they can specify them in arbitrary position, without any experience specific informations.
User tends to turn in the direction of the screen : in that case, sub-space tends to be vertical, and directly relates to the field of view of user. In case where users to not orientate themself in the direction of the screen, sub-space is created horizontally, for indirect interaction.
Gesture for creating and deleting sub-spaces can be parameterized gestures: for most users, these gestures specify both a *command* (create/delete subspace) and some *parameters* of the command (some geometric features such as sub-space location for creation; delete gesture starts within the sub-space that is to be deleted), in the same gesture.
User has proper mental perception of sub-spaces he/she creates Since all users provided delete gestures that start in a location devoted to the sub-space that was previously created, this shows that users have good mental perception of interaction sub-spaces.

7 Conclusion and Future Work

We presented elements of knowledge about mid-air interaction with distant displays. We introduced the concept of *sub-space gestures*, that we think is a good approach to combine mid-air and clutching, while maintaining an interesting design space. We showed that sub-space gestures is, to the highest acceptability, planar and dynamic. Sub-space gestures also have the quality to highlight, within all mid-air possible interaction contexts, some specific subsets, that opens new research directions. Interaction techniques, visual feedback, reachable interaction precision taking into account distance of view, are interesting questions in this context. Also, question of co-located collaboration is an important question, as it is a key feature in the context of distant, non-instrumented, interactive systems.

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